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Clinical Outcomes of Double-Screw Fixation with Autologous Bone Grafting for Unstable Scaphoid Delayed or Nonunions with Cavitary Bone Loss

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Abstract

Objective This study reports on the clinical outcomes of double screw fixation with autologous cancellous bone grafting and early active range of motion for delayed and nonunited scaphoid waist fractures with cavitary segmental bone loss.

Patients and Methods Twenty-one consecutive patients underwent fixation using two 2.2 mm antegrade headless compression screws with autologous distal radius cancellous bone graft. Postoperatively, patients were allowed early active motion with a resting splint until union was achieved. Patients were reviewed radiologically and clinically to assess for fracture union, complications, residual pain, wrist function, and return to work and recreational activities.

Results All but one patient was male, and the mean age was 23 years (range, 15–38 years). The average time from initial injury was 16 months (range, 3–144 months). Nineteen of 21 (90.5%) patients achieved union at a mean of 2.8 months (range, 1.4–9.2 months). Of the patients who failed, one underwent revision surgery with vascularized bone grafting at 10.6 months. The other patient refused further intervention as he was asymptomatic.

Conclusion Double-screw fixation with bone grafting and early active range of motion is a safe and effective technique for management of delayed and nonunited unstable scaphoid fractures with cavitary bone loss. This potentially allows for earlier return to function, without compromise to union rates.

Level of Evidence This is a Level IV, retrospective case series study.

Keywords
- scaphoid fracture
- nonunion
- fixation
- wrist
- bone graft

The scaphoid plays a significant role in the overall kinematics and stability of the wrist.[1] However, it is the most commonly injured carpal bone, responsible for 50 to 80% of all carpal fractures.[2] Due to the extensive articular surface, its unique shape and its tenuous retrograde blood supply, this makes scaphoid fractures susceptible to nonunion.[3] Approximately 10 to 15% of all scaphoid fractures progress on to nonunion, invariably requiring surgical management, as failure to restore stability to the scaphoid eventually leads to predictable degenerative changes and eventual scaphoid nonunion advanced collapse (SNAC).[4]

Scaphoid nonunions are often associated with cystic changes and collapse and it is frequently observed that, after clearance of all the nonunion tissue and correcting the

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scaphoid alignment, there is a degree of bone loss which requires bone grafting to fill in the defect. However, achieving biomechanically stability of the scaphoid with this defect poses two challenges: (1) obtaining adequate bone contact and (2) interfragmentary compression.[5] Compromise in either or both of these two factors can lead to increased instability across the fracture, thus affecting union rates.[1]

Current fixation options include the use of K-wires, single or double headless compression screws and plates.[5–7] We have previously compared biomechanically the latter three fixation options and have shown that both double screws and plate fixation provide significantly greater stability and stiffness, especially in rotation, when compared with single-screw fixation in a scaphoid nonunion model.[5] However, double screws and plate fixation showed no significant differences when compared, in any of the biomechanical parameters.[5]

Putnam et al recently reported good outcomes and high healing rates with volar plate fixation and autologous cancellous bone grafting for scaphoid nonunions with segmental defects.[8] However, with this fixation, there is still the potential disadvantages of plate impingement requiring removal, inability to compress across the fracture and also the higher costs due to the number of screws required.

In the literature, there has only been one previous study by Garcia et al that reported on the use of double screw fixation in a heterogeneous group of patients.[6] In their series, which combined scaphoid nonunions at various locations and the use of different bone grafting techniques, 100% of fractures went on to achieved radiological union, with good clinical outcomes.

Given the paucity of data in the literature, it was the aim of this present study to report on the clinical and radiological outcomes of a consecutive single-surgeon series of patients with scaphoid waist delayed or nonunions who underwent internal fixation with autologous cancellous bone graft and double antegrade compression screw fixation. It was our hypothesis that the use of two screws provides comparable or better union rates to other techniques in the literature and allows earlier commencement of active range of motion and rehabilitation, without compromise to union rates.

Methods

Patients

Between July 2014 and October 2018, patients were identified from a prospectively collected database, having undergone surgery by the senior author (E.T.E.) for a scaphoid delayed-union (3 to 6 months) or nonunion (>6 months). Medical records were retrospectively reviewed. Human Research and Ethics Committee approval was obtained prior to the commencement of any data collection (LNR/15/Austin/186). The following inclusion criteria were applied, delayed or nonunited scaphoid transverse waist fractures with cavitary or segmental bone loss (►**Fig. 1**), more than 12 weeks (3 months) from the index injury, fixation with two 2.2-mm cannulated headless compression screws (Medartis, Basel, Switzerland) and the use of autologous cancellous distal radius bone graft. Patients were excluded if they had features of avascular necrosis (AVN) of the proximal pole, that is, increased sclerosis on X-ray or computed tomography (CT) scan, and if vascularized bone grafting was performed or if the fracture was deemed at the level of the proximal or distal pole. Patients were also excluded if there was a significant humpback deformity and where structural iliac crest bone graft was deemed necessary, in which case, generally a volar approach was preferred by the senior author in both scenarios. Twenty-one patients were subsequently included in the study.

Surgical Technique

In all cases, a dorsal approach was utilized (►**Fig. 2A**). The reason for this was primarily based on the senior surgeon's preference. A curvilinear incision is made just ulna to Lister's tubercle and extended distally in line with the thumb. Dissection was performed down to the extensor retinaculum and the extensor pollicis longus (EPL) tendon was transposed out of its groove. The interval between the extensor digitorum communis and extensor carpi radialis brevis was developed. An oblique capsulotomy was then made in line with the scaphoid, exposing the waist and proximal pole of the scaphoid. At this point, the waist fracture becomes evident. Of note, special care was made not to elevate or dissect of the capsular attachments to the distal pole of the scaphoid, so as to not compromise the

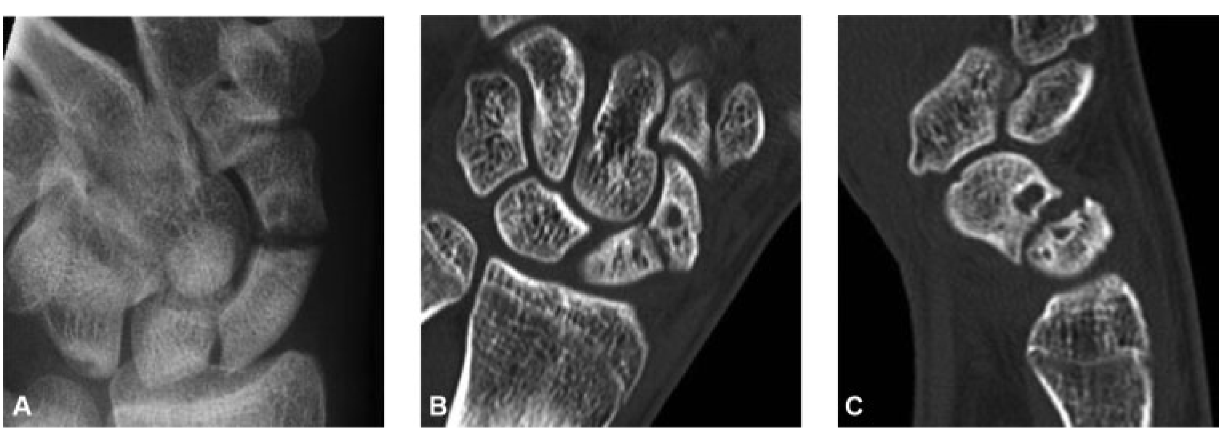

Fig. 1 (**A**) Preoperative anteroposterior (AP) X-rays demonstrating a scaphoid waist fracture nonunion. (**B**) Coronal and (**C**) sagittal CT scans showing the cystic bone loss at the nonunion site. CT, computed tomography.

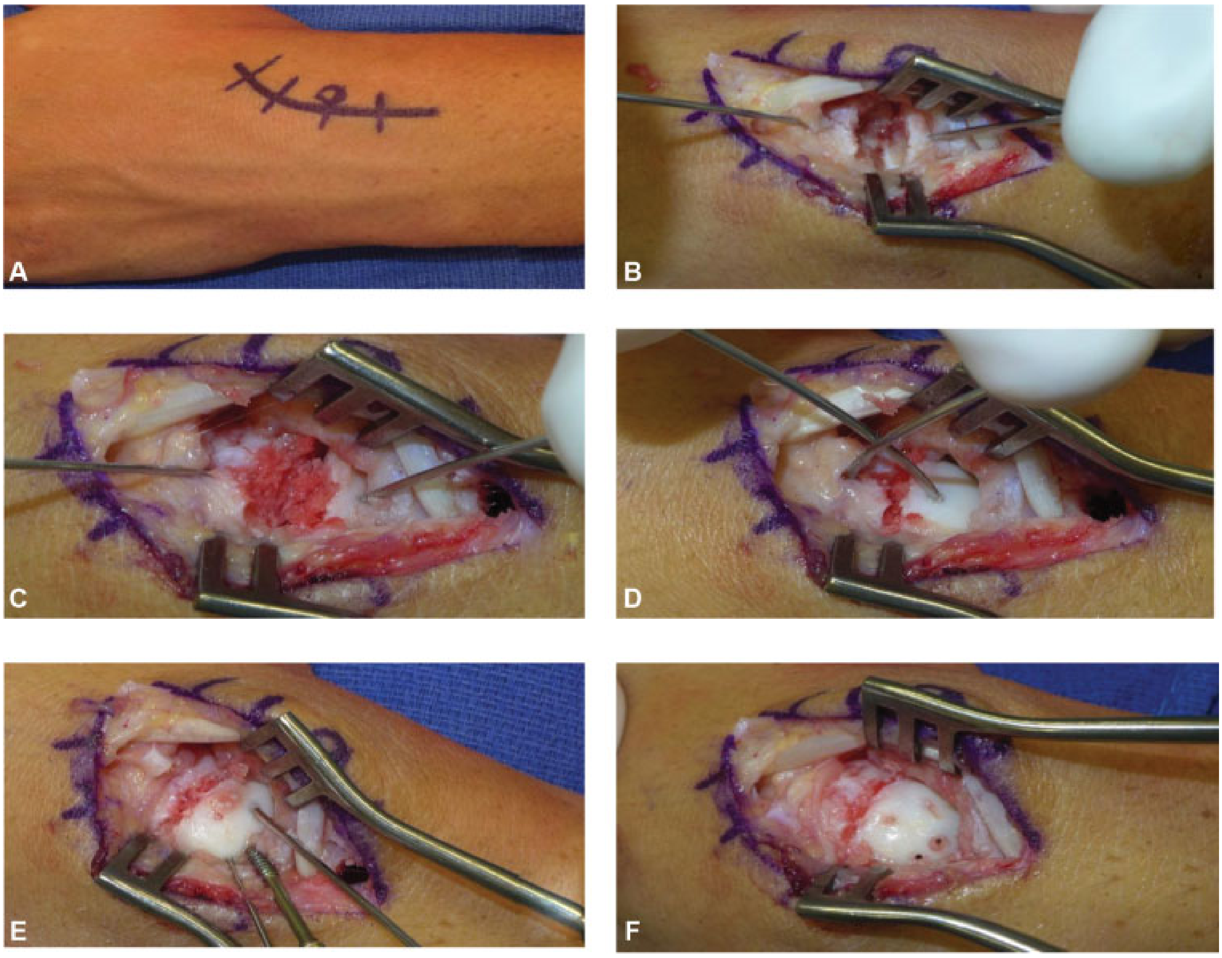

Fig. 2 Surgical Technique: (**A**) dorsal curvilinear incision is made just ulna to Lister's tubercle. (**B**) K-wires are inserted into both the proximal and distal pole to allow the fracture site to be distracted. The fibrous nonunion tissue is curetted and all nonviable bone is removed. (**C**) Distal radius cancellous bone graft is then impacted into the fracture site and the (**D**) scaphoid is then reduced and a stabilizing K-wire is introduced. (**E**) The wrist is then flexed to expose the proximal pole of the scaphoid and two guide wires are inserted toward the scaphoid tubercle. After confirmation on fluoroscopy, two 2.2 mm cannulated compression screws are inserted and (**F**) buried beneath the articular cartilage.

blood supply. K-wires were then inserted into the proximal and distal poles and used as joysticks to distract the fracture and correct the scaphoid alignment and also allow preparation of the fracture site. All necrotic bone and fibrous tissue were debrided using a curette and the goal was to expose healthy appearing viable bone (►**Fig. 2B**).

Cancellous distal radius bone graft was harvested from the proximal extent of the incision, after removal of Lister's tubercle. The bone graft was then compacted by placing it into a 3-mm syringe and compressing it with the plunger. The bone graft was then inserted and packed into the defect and the fracture was then reduced using the K-wires as joysticks and the scaphoid alignment was corrected. A temporarily cross K-wire was inserted to stabilize the fracture (►**Fig. 2C, D**). The wrist was then flexed to expose the proximal pole of the scaphoid and two guide wires were inserted for placement of the cannulated screws. Both guide wires were placed in an antegrade fashion, starting just adjacent to the scapholunate (SL) ligament, directed toward the scaphoid tubercle (►**Fig. 2E**). A gap of approximately 5 mm was ideal between the two screws at insertion and maximal divergence was preferred if possible. Convergence of the wires was avoided. Fluoroscopy was performed to confirm the fracture reduction and the position of the wires. A depth gauge was used to determine the length of screw, and the longest screw possible, without being prominent, was chosen. Both screws were then inserted without the need for over drilling, with screw heads placed beneath the articular surface (►**Fig. 2F**).

The joint was then thoroughly irrigated and the capsulotomy was closed with absorbable sutures. The EPL tendon was transposed superficial to the retinaculum after it had been repaired. The subcutaneous layer and skin were closed in a standard fashion.

Postoperative Rehabilitation

All patients underwent the same postoperative protocol. Patients were placed in a below elbow thumb spica plaster splint for approximately 10 to 14 days. At the first postoperative appointment, patients were then placed into a resting removable thermoplastic thumb spica splint and commenced early active range of motion of the wrist, in particular, gentle dart throwing motion progressing to full active motion of the wrist. Patients were advised to not perform any lifting or gripping with the operative hand.

Clinical and Radiological Follow-up

Patient were routinely reviewed at 6 to 8 weeks postoperatively, where union was assessed by either plain radiographs or CT scans (►Fig. 3). If union had not been achieved at that time, patients were then reimaged every 4 weeks until union was confirmed. CT scans were reconstructed along the longitudinal axis of the scaphoid and the Singh criteria was utilized for assessment of fracture union. This involved having more than 50% of trabecular bridging on three or more slices of the scan (►Fig. 3C, D). To confirm union using plain radiographs, trabecular bridging on three views (anteroposterior, lateral, and scaphoid view) was assessed (►Fig. 3A, B). If union was not clear or equivocal on the plain radiographs after 8 weeks, a follow-up CT scan was performed. Patients remained in the thermoplastic splint without return to full weight bearing until union was confirmed.

Patient records were reviewed for range of motion at the time of their latest follow-up, including wrist flexion and extension and forearm pronation and supination.

Fig. 3 (A) and (B) AP and lateral X-rays demonstrating union of the scaphoid fracture nonunion at 8 weeks postoperatively. (C) and (D) Coronal and sagittal CT scans confirming fracture union. AP, anteroposterior; CT, computed tomography.

Attempt was made to contact all patients for assessment of current status. Sixteen patients were contactable by phone and in these patients, patient-reported outcome measures (PROMs) were obtained, including the disabilities of the arm, shoulder, and hand (DASH) score, the modified Mayo wrist score (MMWS), and the patient-rated wrist evaluation (PRWE).

Preoperative and postoperative X-rays and CT scans were analyzed, and assessment was made of the SL angle, radiolunate (RL) angle, sagittal intrascaphoid angle (ISA), and the scaphoid height/length (H/L) ratio.[9] Preoperatively, the mean SL angle was 68 degrees ± 14 (normal, 30–60 degrees), the mean RL angle was −13 degrees ± 10 (normal, 15 to −15 degrees), the mean sagittal ISA was 52 degrees ± 7 (normal, <35 degrees), and the mean H/L ratio was 0.67 ± 14 (normal, <0.6; ►**Table 1**).

Statistical analysis was performed using SPSS Version 20.0. (IBM Corp., Armonk, NY). Mann–Whitney testing for nonparametric data was performed to analyze differences between preoperative and postoperative intercarpal angles. Statistical significance was set as $p < 0.05$.

Results

The average age at surgery was 22.7 years ± 6.2 (range, 14.9–37.9 years). The average time to surgery from the initial injury was 16.2 months ± 30.5 (range, 3.0–144 months). No patients had had any prior surgery. Twenty patients were male, and one was female, and all were right-handed. In 13 patients (62%), the injury involved with dominant wrist. The mean follow-up period was 24.7 months (range, 3.6–66.2 months ►**Table 2**).

At the time of latest follow-up, nineteen of 21 patients (90.5%) had achieved union. This was confirmed radiologically at an average of 2.9 months (range, 1.4–9.2). Initial radiographic union was assessed using CT scan in 16 patients and by plain radiographs in 5. However, all 19 patients ultimately obtained a CT scan by latest follow-up, which demonstrated scaphoid union. Two patients continued to smoke during the postoperative period. One of these patients had persistent nonunion at the time of latest follow-up (13 months). The other patient eventually achieved union, but this took 9.2 months, almost 7 months longer than the average period for other patients.

Table 1 Preoperative and postoperative radiographic data

	Preoperative X-rays ($n = 16$)		Preoperative CT scan ($n = 14$)		Postoperative X-rays ($n = 21$)		Postoperative CT scan ($n = 21$)	
Patient	RL angle	SL angle	Sagittal ISA	H/L ratio	RL angle	SL angle	Sagittal ISA	H/L ratio
1	−5	60	[a]	[a]	−5	50	15	50
2	−15	80	45	65	0	50	15	55
3	−15	69	[a]	[a]	0	45	30	64
4	−10	80	55	68	−15[b]	65[b]	55[b]	70[b]
5	[a]	[a]	[a]	[a]	−20[b]	80[b]	34[b]	57[b]
6	−20	70	55	67	−5	55	40	60
7	−10	65	[a]	[a]	−5	60	40	55
8	−10	65	48	50	−5	60	30	50
9	0	65	53	73	0	60	40	54
10	−20	75	60	70	−5	45	25	50
11	0	50	40	60	0	50	40	60
12	[a]	[a]	[a]	[a]	0	50	25	50
13	0	50	60	70	0	45	35	50
14	0	40	40	60	0	40	40	60
15	[a]	[a]	[a]	[a]	0	45	40	60
16	−20	65	53	73	−10	50	30	60
17	[a]	[a]	[a]	[a]	−10	45	32	55
18	−30	90	50	70	−10	45	20	50
19	−20	90	65	77	0	47	30	50
20	−25	67	50	65	−10	45	20	52
21	[a]	[a]	55	71	0	45	10	58
Mean ± SD	−12.5 ± 9.7	67.6 ± 13.8	52.1 ± 7.3	67.1 ± 6.9	−4.0 ± 4.8	49.9 ± 6.7	30.6 ± 11.1	55.7 ± 5.7

Abbreviations: AH/L, height/length; CT, computed tomography; ISA, intrascaphoid angle; RL, radiolunate; SD, standard deviation; SL, scapholunate.
[a]Preoperative X-ray or CT scans not available for evaluation.
[b]Patients went on to develop nonunion.

Table 2 Patient characteristics, time to union, and time of follow-up

Patient	Sex	Hand dominance	Mechanism	Age at surgery (y)	Time to surgery (mo)	Time to union (mo)	Follow-up time (mo)
1	Male	Nondominant	Snowboarding	20.6	18.0	1.8	38.3
2	Male	Dominant	FOOSH	18.8	6.0	2.0	14.9
3	Male	Dominant	FOOSH	22.6	23.0	9.2	66.2
4	Male	Nondominant	FOOSH	22.3	3.5	Nonunion[a]	13.0
5	Male	Nondominant	Impact	19.1	6.7	Nonunion[b]	15.8
6	Male	Dominant	Pushbike	25.3	4.3	2.3	11.2
7	Male	Nondominant	Football	21.7	3.0	2.3	48.1
8	Male	Dominant	Impact	14.9	6.7	3.1	42.2
9	Male	Dominant	Snowboarding	28.4	32.3	2.3	41.5
10	Male	Dominant	FOOSH	28.0	3.0	1.6	11.7
11	Male	Dominant	FOOSH	36.6	3.3	1.4	37.1
12	Male	Dominant	Motorbike	16.2	5.2	3.2	3.6
13	Male	Nondominant	FOOSH	16.6	19.4	2.5	6.4
14	Male	Dominant	FOOSH	24.1	3.0	2.0	28.2
15	Male	Nondominant	FOOSH	37.9	144.0	3.0	27.7
16	Female	Nondominant	FOOSH	16.3	6.0	3.0	12.0
17	Male	Dominant	FOOSH	17.2	3.0	3.0	45.5
18	Male	Dominant	FOOSH	21.1	9.0	3.0	12.0
19	Male	Nondominant	FOOSH	27.0	24.0	2.0	6.0
20	Male	Dominant	FOOSH	20.2	4.0	2.0	12.0
21	Male	Dominant	FOOSH	21.8	12.0	3.5	7.4
			Mean ± SD	22.7 ± 6.2	16.2 ± 30.5	2.8 ± 1.7	24.7 ± 17.7

Abbreviations: FOOSH, fall on outstretched hand; SD, standard deviation.
[a]Asymptomatic thus no further surgery performed.
[b]Underwent revision with vascularized bone grafting procedure at 10.6-month postoperatively.

On evaluation of the postoperative X-rays and CT scans, there was statistically significant improvements in all radiographic parameters when compared with preoperatively. The mean SL angle improved from 68 to 50 degrees ($p < 0.05$), the mean RL angle improved from -13 to -4 degrees ($p < 0.05$), the mean sagittal ISA decreased from 52 to 31 degrees ($p < 0.05$), and the mean H/L ratio decreased from 0.67 to 0.56 ($p < 0.05$; ►**Table 1**).

The mean range of motion at the time of their latest follow up was 85 degrees of wrist extension and 85 degrees of wrist flexion. All patients had regained full pronation and supination. Essentially, all patients had regained full active range of motion, symmetrical to the contralateral side. Even in the two patients that did not achieve union, their range of motion was not limited and was symmetrical to the other side. Of the 16 patients that were contactable for functional outcome measures, 2 of these patients had not achieved union. Therefore, for the 14 patients (74%) who had united, their mean DASH score was 4.8, the mean PRWE score was 11.4, while the mean MMWS was 88.7. These scores represent excellent overall functional outcome.

With respect to the two patients that had persistent nonunion, one subsequently underwent revision surgery at 10.6 months and had a vascularized pedicle bone graft procedure using the 1,2 intercompartmental supraretinacular artery (ICSRA). He eventually went onto union and regained full functional recovery. The other patient underwent 3 months of a low intensity pulsed ultrasound bone stimulator, commencing at 6 months postoperatively. This was not successful, and the patient was offered revision surgery. Of note, this patient was a smoker, which most likely contributed to the poor healing. However, despite the nonunion, he did not have any pain or limitations in function and elected to cease treatment. Follow up X-rays after 3 months of cessation of treatment did not demonstrate any signs of hardware loosening or further fracture displacement. He has since been lost to follow-up.

There was one patient who had slightly prominent screws proximally and subsequently underwent removal due to pain on wrist extension, which was resolved. There was no evidence of any other intra-articular screw penetration, in particular, the scaphocapitate joint.

Discussion

The management of scaphoid fractures with cavitary segmental defects is challenging, with stability of the fixation being a key factor in achieving successful bony healing. While various other factors contribute to the risk of persistent nonunion, such as smoking, time to surgery, vascularity of the proximal pole and location of the fracture, the stability of the fixation is one factor within the surgeon control.[5,10] At present, it is widely accepted in the literature, that the gold-standard of treatment for scaphoid nonunion is internal fixation using a single headless compression screw and autologous bone grafting. However, when there is segmental bone loss across the fracture, achieving bone to bone contact and compression across the two ends can be challenging. We have previously shown in a biomechanical study, that in a scaphoid nonunion model with segmental bone loss, the use of a single compression screw does not adequately resist rotational forces when compared with other constructs such as double screws or scaphoid plate fixation.[5] This has been further supported by several other biomechanics studies that have shown similar results.[11,12]

In this present study, we report on the clinical outcomes of double screw fixation for the management of delayed or nonunited scaphoid waist fractures with segmental bone deficiency. To our knowledge, there has only been two other studies that have reported on the use of double screw fixation for scaphoid fracture nonunions.[6,13] Garcia et al demonstrated a union rate of 100% with no postoperative complications in a series of 19 patients.[6] However, in their study, the indications for surgery were widely heterogeneous with regard to fracture location, type of bone grafting used and the surgical technique. In their study, they included patients with proximal, distal, and waist fractures, various bone grafting techniques, as well as a combination of volar and dorsal surgical approaches. Nevertheless, all patients in their cohort went onto successful union. In another study by Quadlbauer et al, they compared single versus double plate fixation with iliac crest bone graft in a series of 42 patients with scaphoid waist nonunions.[13] They showed that double screws (83%) or plate fixation (85%) had a higher union rate when compared with single screw fixation (60%). However, among these patients, some had adjunctive extracorporeal shockwave therapy, which did not appear to significantly improve union rates.

The strength of our study is the homogenous nature of our patient cohort. All patients in this series had a transverse scaphoid waist fracture that was either delayed (3 to 6 months) or nonunited (>6 months) and exhibited cavitary segmental bone loss at the fracture site. All cases were treated by a single surgeon in a similar fashion, with antegrade double screw fixation through a dorsal approach with cancellous distal radius bone graft. Furthermore, all patients underwent identical postoperative rehabilitation with early commencement of active range of motion of the wrist.

The overall union rate in this present series was 90.5% (19 of 21 patients). This is comparable to the current literature, where overall union rates for operatively treated scaphoid waist nonunions has been reported to be in the order of approximately 80 to 90%. In a large systematic review by Pinder et al, they analyzed more than 850 patients who underwent internal fixation using a single screw, and found an overall union rate of 88%.[4] Furthermore, Munk and Larsen analyzed the outcomes of 5,246 nonunions that were managed with supplemental bone grafting in addition to internal fixation.[14] Of these, 2,669 underwent nonvascularized bone grafting with internal fixation and the union rated was reported to be 84%.

Overall, there were no significant technical complications related to the insertion of the screws. In only one case, the screws were noted to be prominent proximally resulting in discomfort on wrist extension. As the screws are placed under vision and inserted beneath the articular cartilage, the resultant prominence may be related to a degree of collapse causing the screws to migrate proximally. One method, to mitigate this, is to consciously undersize the screws and ensure that the head is well buried, but at the same time, not protruding distally. Furthermore, given that the screws are not inserted along the mid axis of the scaphoid, but rather paracentrally, the length of the screws are usually not within the expected range of 22 to 26 mm, but often shorter, between 18 and 22 mm. In addition, care should also be taken not to breach the scaphocapitate joint, when passing the ulna most wire. This can be avoided by placing the entry point more radial on the proximal pole of the scaphoid. As the scaphoid is "**C**-shaped" in the coronal plane, starting the wire too ulna ward runs the risk of entering the scaphocapitate joint as the wire is passed to the distal pole.

The large majority of biomechanical studies on fixation methods for scaphoid nonunions have only analyzed stability in flexion and extension and under compressive loads.

However, these studies neglect the complex rotation motion of the scaphoid during physiological wrist motion. Based on previous work, we, along with other authors, have shown biomechanically that double-screw fixation allows for two points of fixation across the scaphoid, therefore providing greater resistance to torsion moments and hence improved stability, in comparison to single screw fixation.[5,11] The use of two 2.2-mm compression screws were significantly more stable compared with a single 3.0-mm compression screw.[5] This is most relevant when the fracture is unstable and there is a gap in bony contact, such as in the case of bone loss or resorption. Therefore, based on this data, we were confident to allow our patients to commence early active range of motion of the wrist following fixation. From our results, we found that union rates were not compromised, when compared with the literature, and that we could accelerate patient rehabilitation with early active motion.

The placement of the screws within the scaphoid is important, and it is often difficult to achieve optimal screw placement. Garcia et al suggested, when placing two screws, they should be parallel to the long axis of the scaphoid, and not directly adjacent to each other in the coronal plane. They should also be separated, at minimum, by the diameter of the screws that are to be inserted.[6] However, it is currently unclear as to which is the best orientation in which to arrange the two screws, for example, in the anteroposterior plane or in the radial–ulna plane. Lee et al suggested that screw placement should be based on regional bone strength.[15] They conducted a regional analysis of the bony microarchitecture of the scaphoid measuring bone density and bone quality, to give an overall indication of bone strength. They found that the axis running from the ulnar side of the distal tuberosity to the radial side of the proximal pole, in addition to the ulnar side of the scaphoid waist had the highest bone strength parameters based on the osseous microarchitecture. From this analysis, it was proposed that screws should be placed through these regions to achieve maximal strength of fixation.[15] In this current series, all screws were inserted in an antegrade fashion, with the goal of screw placement to be along the longitudinal axis of the scaphoid, maximally separated in the coronal plane. However, further biomechanical studies are required to test whether this is the optimum position of screw placement.

Limitations

The inherent limitations of this study are its retrospective nature, the relatively small study size and the absence of a comparison group. However, we feel that this represents the only study to date that reports on the use of double screw fixation in a homogenous group of patients with scaphoid waist nonunions. In the future, well-organized, randomized control trials need to be performed to compare single versus double screw fixation for scaphoid waist nonunions, to determine the increased theoretical stability translates to better union rates and accelerated rehabilitation and functional outcomes.

Conclusion

In conclusion, our results demonstrate that double screw fixation with autologous bone grafting of unstable delayed or nonunited scaphoid waist fractures with cavitary bone loss is a safe and effective technique, which allows early active range of motion, without compromise to overall union rates.

Ethical Approval

This project was approved by the Austin Hospital, Human Research Ethics Committee, HREC No. LNR/15/Austin/186.

Funding

None.

Conflict of Interest

None declared.

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